Physics 262

Lab #6: Optical Fiber Amplifier

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Abstract

This experiment made use of an optical spectrum analyzer to characterize the operation of an erbium doped optical fiber amplifier. Plots of the fiber's gain are shown in the experimental results section. Plots of gain as a function of pump power are also shown, and the threshold pump power required to produce unity gain was determined to be between 1.5 mW and 3.0 mW.

Introduction

One of the problems with fiber optic communications is that over large distances the signals will inevitably diminish in power. In order to restore it to the level necessary to avoid errors in transmission, relay devices must be build to power and re-send the signal. This can be done electrically, but a more reliable and faster technique is to use optical fiber amplifiers in order to stimulate additional emission in time with the carrier frequency. The erbium doped fiber used in this experiment is a device capable of exactly this task.

Theoretical Background

The erbium doped optical fiber amplifier operates by absorbing energy from a generic laser source (in the case of this experiment, a 980 nm laser pump) and then releasing that energy when stimulated by a particular laser signal at another frequency. There are numerous reasons why laser amplification might be necessary, the simplest of which is to replace losses in signal strength as a signal travels along an optical fiber.

The key to the amplification lies in the erbium doped ions of the amplifying fiber. When these ions are excited by the pump laser's radiation, they can remain excited for a relatively long lifetime; long enough for them to go into stimulated emission when they encounter the light signal.

The electrons of erbium ions are particularly prone to small excitations because the ion has an unfilled 4-f electron shell. This energy level is split by electron-electron and spin-orbit interactions into many degenerate levels. This creates opportunities for the amplifier to emit various frequencies based upon the frequency of the signal which excites it. The lower wavelength pump provides a higher amount of energy than the higher wavelength signal, and thus the same pump can be used for a variety of amplifications.

Experimental Procedure

Apparatus

Tunable 1525 nm - 1600 nm laser source, 980 nm pumping laser, 980 nm/1550 nm wavelength division multiplexer, 1550 nm optical isolator, erbium doped fiber (approx. 18.5 m), standard fiber and connectors, white light source, optical spectrum analyzer

Procedure

The first objective of the experiment was to gain familiarity using the optical spectrum analyzer. A fiber was run from the output of the 980 nm pump to the 980 nm input of the multiplexer. The 1550 nm multiplexer input was kept capped. The output of the multiplexer ran to the erbium fiber and from there to the optical spectrum analyzer. Results of the 1500 nm – 1620 nm range were saved to disc for various pump currents. Data was also collected over the 500 nm– 650 nm range to look for the characteristic green emission of the stimulated erbium.

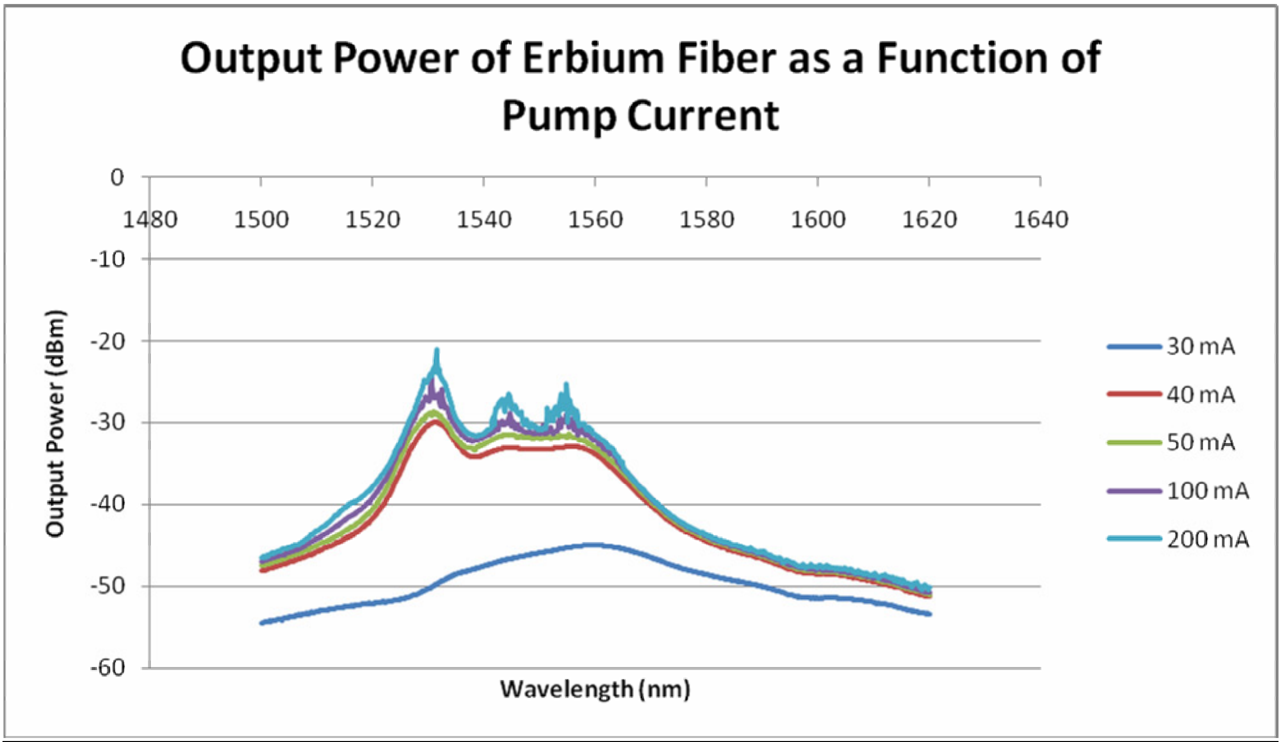
The next task was to make a check of the performance of the individual network components. The individual lengths of fiber connections, the optical isolator, and the erbium doped fiber were all stimulated by the white light source and examined over the range of 500 nm to 1750 nm.

After attaining a grasp of the basic controls for the OSA, it was time to begin calculating the gain of the optical fiber amplifier. First, the tunable laser was attached directly to the OSA to correlate laser currents to optical output power at a variety of frequencies. After establishing this baseline, the full amplifier was set up per the diagram outlined in the lab notebook: that is, the tunable and pump lasers were sent through the multiplexer, the erbium fiber, and the optical isolator. Output power of the system was observed for 0 mA, 100 mA, and 200 mA of pump laser current. This was compared to the base power produced by the tunable laser to determine how much gain the pump adds at various frequencies.

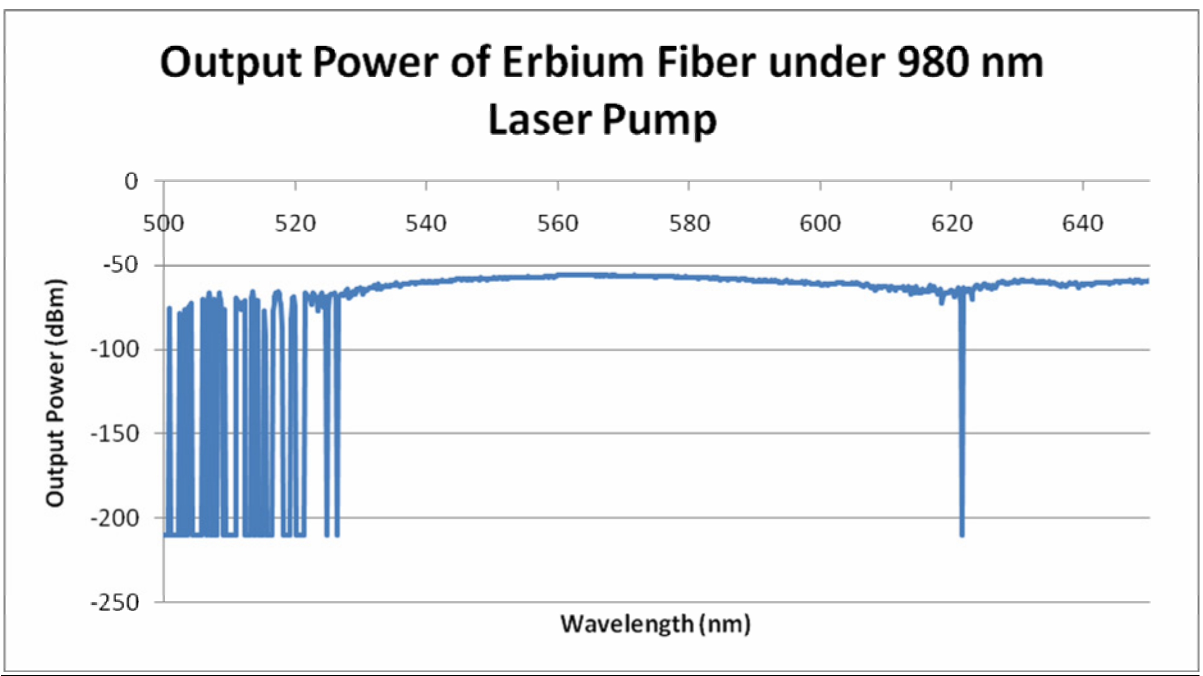
Lastly, the output power was determined as a function of laser pump power with the intention of determining the threshold pump power, that is, the pump power at which the amplifier system produces unity gain. To help in this task, data was collected to correlate pump laser current with direct optical power by use of the OSA.

Experimental Results and Discussion

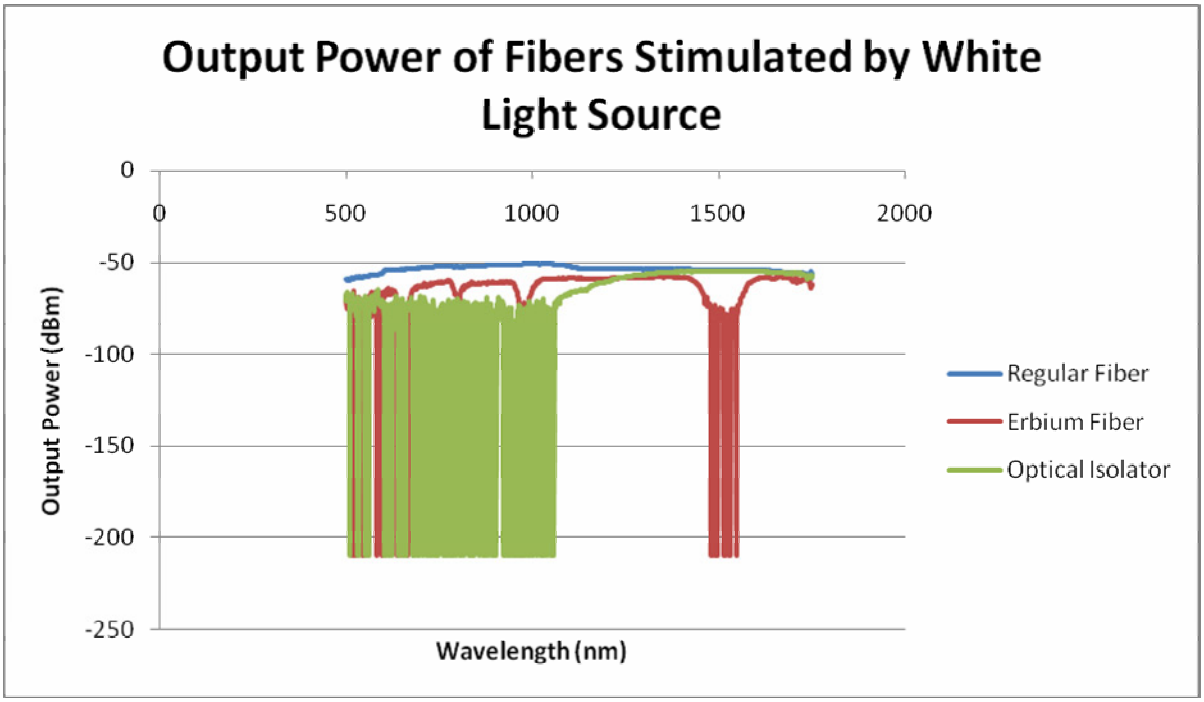
Here are the results of the first OSA measurements for the erbium fiber output when stimulated only by the 980 nm pump laser. Note that above a certain threshold (starting somewhere between 30 mA and 40 mA) there seems to be a fairly consistent response regardless of pump power. Also noteworthy is the presence of defined peaks in the output power. These represent natural emission wavelengths for the erbium doped fiber.



Also, here are the results of the same experiment focused on lower wavelengths:



When the three types of fibers were stimulated by the white light source, it was shown that the regular fiber showed no particular preference over which wavelengths it passed, the optical isolator exhibited sharp rejection of light at wavelengths less than about 1060 nm, and that the erbium laser showed pockets of rejection at its intended frequencies of operation. These conclusions can be observed from the following plot:



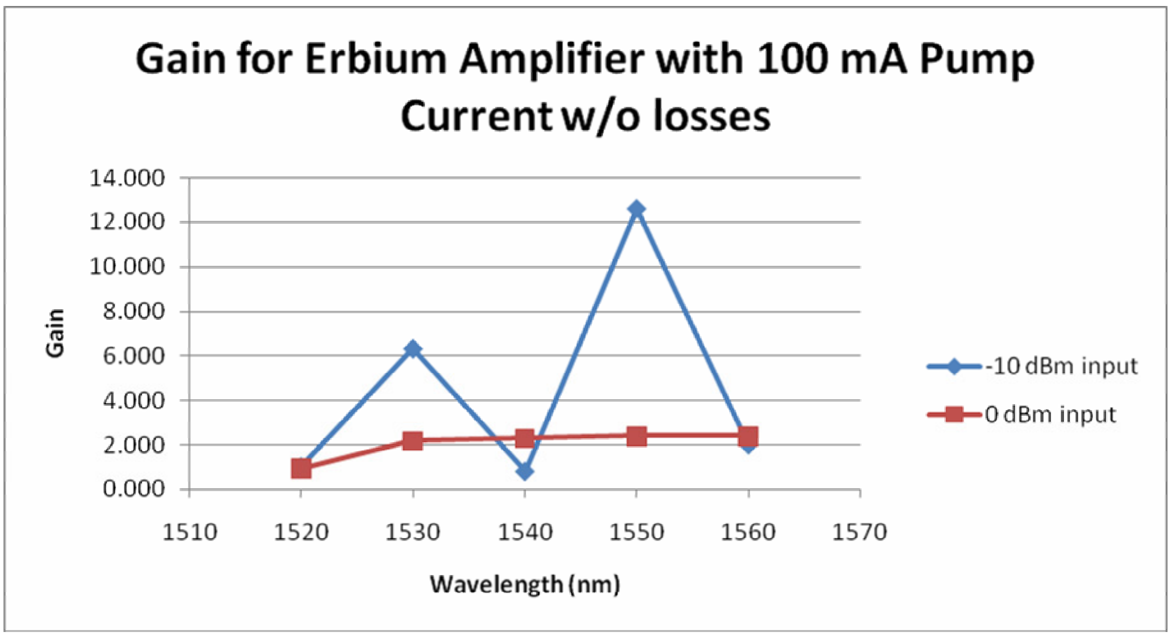
To calculate the gain of the amplifier, the output power of the system is divided by the input power produced by the laser when directly connected to the OSA. In the first part of the experiment, the currents required to produce 0 dBm or -10 dBm of direct-connection output power were recorded, and these currents were used to produce the following table of output powers for a those standardized input power.

Input Power (dBm)	Pump Current (mA)	Wavelength (nm)				
		1520 nm	1530 nm	1540 nm	1550 nm	1560 nm
0	200	0.0	7.0	6.0	6.5	6.0
0	100	-0.3	3.4	3.6	3.8	3.8
0	0	-20.0	-24.0	-19.0	-12.4	-12.8
-10	200	-10.0	1.0	-10.0	2.0	-6.0
-10	100	-10.0	-2.0	-11.0	1.0	-7.0
-10	0	-46.7	-57.0	-53.8	-28.6	-33.5

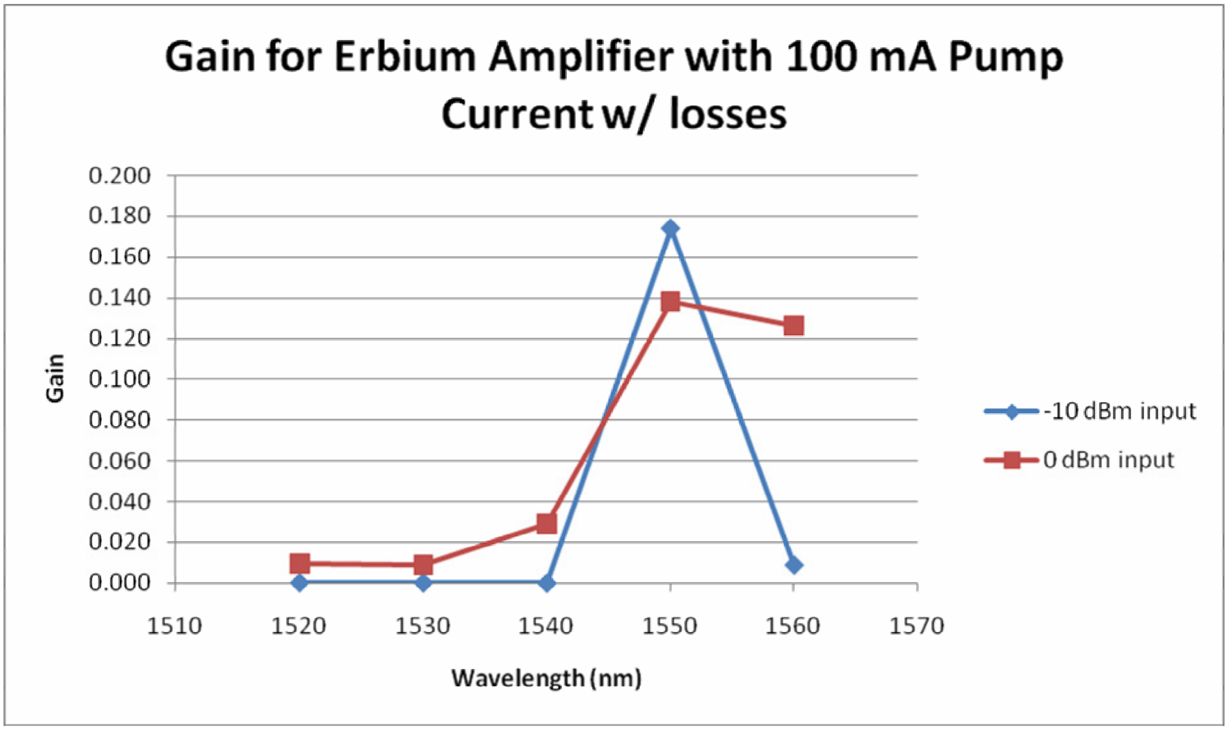
By dividing the output power by the input power, a new table of values can be obtained corresponding to the gain of the system. It was necessary to convert from dBm to mW to calculate gain.

Input Power (dBm)	Pump Current (mA)	Wavelength (nm)				
		1520 nm	1530 nm	1540 nm	1550 nm	1560 nm
0	200	1.000	5.012	3.981	4.467	3.981
0	100	0.933	2.188	2.291	2.399	2.399
0	0	0.010	0.004	0.013	0.058	0.052
-10	200	1.000	12.589	1.000	15.849	2.512
-10	100	1.000	6.310	0.794	12.589	1.995
-10	0	0.000	0.000	0.000	0.014	0.004

Here is a plot of the gain data:

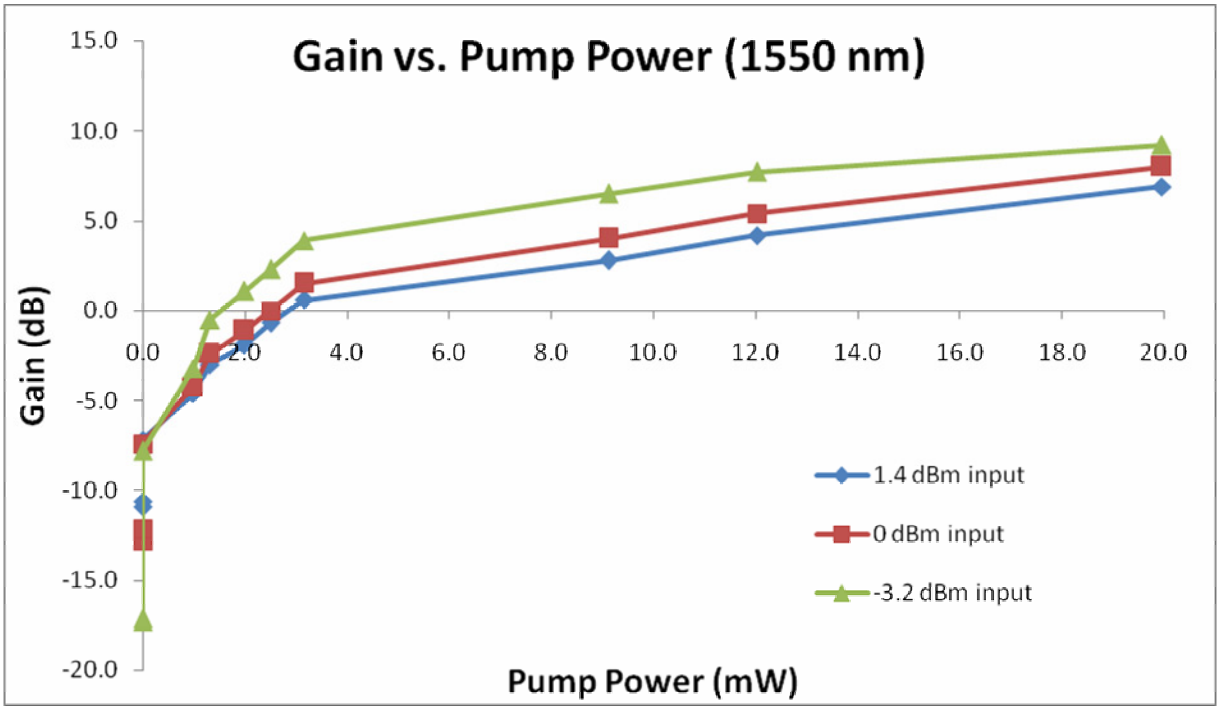


It appears that the -10 dBm, 1540 nm data point is some kind of outlier that appears for both pump currents. One possible explanation is that a shift in modes in the tunable laser caused there to be a sudden decrease in the input power after the current was set at the proscribed amount. This would have caused the resultant gain to be much lower. Below are the gain values for the 100 mA pump adjusting for losses when the pump was turned off (by multiplying the gain value by the gain when the pump is turned off).



The threshold pump power is the level of pump power required so that the amplifier is transparent, that is, so that it produces unity gain. Ideally, the threshold pump value should be independent of the signal power. The following data was while running the tunable laser at 1550 nm.

Pump Current (mA)	Pump Power (dBm)	Input Power (dBm)		
		1.4 dBm	0.0 dBm	-3.2 dBm
0	-64.0	-9.5	-12.8	-20.5
10	-35.4	-9.2	-12.1	-20.3
20	-20.2	-5.8	-7.4	-11.0
25	0.0	-3.2	-4.2	-6.4
30	1.2	-1.6	-2.4	-3.7
35	3.0	-0.5	-1.1	-2.1
40	4.0	0.7	0.0	-0.9
50	5.0	2.0	1.5	0.7
75	9.6	4.2	4.0	3.3
100	10.8	5.6	5.4	4.5
200	13.0	8.3	8.0	6.0



The plot show threshold pump power 1.5 mW and 3.0 mW (the pump power was converted from dBm to mW to better illustrate the threshold point).

<u>Summary</u>

The threshold pump power was shown to be between 1.5 mW and 3.0 mW (1.8 dBm and 4.8 dBm) for three values of input power. The gain determined for the erbium doped amplifier is shown in the experimental data section, but may have suffered significant inaccuracies in measurement due to instability in the tunable laser at certain frequencies as well as spontaneous emission of the erbium fiber. Nonetheless, the experiment served to illustrate the concept behind optical amplifiers as well as to give visible significance to the idea of spontaneous emission.